NET HERD PRODUCTIVITY AS A SELECTION OBJECTIVE

T.C. Cartwright

Animal Breeding and Genetics Section, Animal Science Department,
Texas A&M University, College Station, Texas. 77843-2471

Producers of livestock and livestock products seeking to increase productivity or production efficiency, may make changes in the environment and in the livestock. Production efficiency is defined here as the output of a livestock herd or flock divided by the input of production resources (O/I). Since economic return is usually the measure of final concern, O/I may be put in economic terms such as sales income divided by production costs. The environment is defined here in broad terms to include the nutrition and source of nutrition such as pastures, climate and its direct and indirect effects, management and health. Also, since O/I may be viewed in economic terms, part of the production environment includes economic effects such as marketing strategy and cost and availability of money. The livestock, or the returns from livestock, of course respond to the environment and its changes. Changes in the livestock to increase O/I are in a sense, made so that the response to the environment will be to require less input or to produce more output, or both. We change the potential of our livestock to respond to the environment by selection; i.e., we change them genetically. There may be selection of species, selection of breeds, and finally, selection of individual animals.

There is variability in the production environment; it is different from place to place and changes from time to time (especially when the economic element is included). There is also genetic variability among our livestock. The challenge is to select and breed our livestock so that they best match the production environment. Determining selection criteria to accomplish this objective is complicated by the many variables involved and by the fact that we are always selecting and breeding for a future and uncertain environment.

Livestock breeders with little or no knowledge of the science of genetics have molded livestock to an amazing degree. For example, recall the different breeds of sheep, e.g. fine wool vs. long wool, and different breeds of cattle, e.g. beef vs. dairy, that were developed before the rediscovery of Mendelian genetic principles in 1900. From basic genetic principles, animal geneticists have developed population and quantitative genetic theory and the applied field of animal breeding. Animal breeding provides a basis for understanding the genetic process and ways to accelerate genetic change through selection and breeding. The increase in genetic potential for milk production of dairy cows in the United States is an example of dairy cattle breeders and animal geneticists collaborating to effect major increases in milk production, a process that has accelerated in the past few years (Powell and Wiggans, 1982). Poultry breeding and swine breeding organised along lines similar to large seed companies are other illustrations of major accomplishments reflecting contributions of animal geneticists.

With the knowledge available in animal genetics, aided by developments in physiology (e.g. frozen semen, multiple ovulation, embryo transfer and frozen embryos) that enhance the manipulation of germplasm, we breeders and geneticists might ask ourselves if the level of performance (O/I) of current genetic stocks is consistent with our capabilities. This question appears to me to be especially relevant to livestock that are managed under more extensive grazing conditions. In the United States, there are at least some cattle breeders of the opinion that the native bison (American buffalo) or the Texas Longhorn virtually unselected by man, are almost as efficient as our improved breeds in extensive range production conditions. Why is there an apparent impasse or, at least, less improvement to date than appears to have been possible with extensively produced livestock (beef cattle, sheep and goats)? Substantial genetic improvement will require collaboration between the breeders and the geneticists and perhaps some changes in approach from both groups. I shall illustrate my points mostly by reference to beef cattle.

Genetic change that results in increased net efficiency is limited by several constraints. One is the fact that breeding herds are very dispersed in the hands of many different breeders with different goals. Another is that the production process is very complex and, with variability in the production environment from area to area and from time to time, there is opportunity for many genetic-environmental interactions. That is, the genotype that tends to maximise O/I at one time or place may be different for another time and place. Some important environmental effects may be exogenous to the production process. For example, in the United States, the Meat Grading Service is contemplating again changing carcase grade standards so that a lower percentage of fat is required for our prime, choice and good grades. The cattle that are presently genetically optimal for growth and maturing rates, and therefore reach the correct degree of fatness at the optimal weight and age, will certainly not be the same genotypes that will be optimal for the proposed standards.

Interactions may also occur within the herd because different traits are optimal for different classes. Objective, metric characters usually considered in beef cattle selection are designated for the convenience of man and are often interrelated. These characters may be divided into two general types: primary and ancillary (Cartwright, 1980). I classify three characters as primary because these characters have predominant, pervasive effects; these are size, maturing rate and milk production. These primary characters have pervasive, correlated effects; i.e. they affect or are affected by many other characters (Cartwright, 1979a,b). Ancillary characters include reproductive soundness, calving ability, bone/muscle/fat ratio, structural soundness, adaptability, disease and parasite resistance, temperament, colour and horned condition.

Size is a composite character that is intended here to relate to structural size; it is conveniently characterised by body weight at maturity, at a given body composition, especially for fat and fill. Generally, as genetic size potential increases, rate of gain potential increases and degree of maturity, including degree of finish, at any age decreases (Taylor, 1968). Cow size is important because of effects on growth rate, maturing rate and weight, and therefore on feed requirements (stocking rates) for maintenance and growth and age at first calf. The nutrients consumed by cows are the major expense related to beef production. Cow size is also important because of the genetic potential for growth and maturing rates transmitted to her progeny. Level of milk production affects nutrient requirements, degree of fatness, and breed-back of the cow as well as weaning weight and finish of her calf. Maturing rate, independent of size, affects age at puberty and degree of finish at any age, and therefore age at first calf and breed-back.

Size and milk production potentials can be changed relatively easily by selection (i.e. heritability is in the medium to high range). Maturing rate independent of size is much more difficult to measure and to change by selection. Breeds exist which combine various size and milk production potentials and to some degree, differences in maturing rate. Examples of contrasts are Charolais vs. Angus for size (currently in the United States many Angus overlap Charolais), Simmental vs. Hereford for milk, and Zebu vs. European breeds for maturing rate.

Keeping these primary characters in mind, beef cattle production may be divided into two basic phases: Phase I, Reproduction and Phase II, Weight Production (Cartwright, 1970). Phase I may be termed cow-calf production and primarily involves increases in numbers, although weight increase is also involved. Phase II involves increase in weight and proportion of finish or fat. Phase I includes principally cow characters; my listing of desired traits is:

Adapted and hardy	High fertility, easy calving
Low maintenance (smaller size)	Moderate milk production
Early puberty	Productive longevity

Phase II includes principally meat animal characters; my listing of desired traits is:

Fast, efficient growth (larger size)
High cutout, meatiness, desirable carcase

The traits that contribute to efficiency for Phase I are not always compatible with those traits that contribute to efficiency in Phase II. Obviously, basing selection objectives solely on either the desired cow herd traits or desired meat animal traits is not logical since each includes only components of total, complex production systems.

These complexities suggest that there may be pluses and minuses for changing any character either up or down. Selection criteria must be based on characters and practised by keeping or rejecting individual animals. Therefore we usually conceive of characters in terms of individuals, but when individuals are aggregated into production units, or herds, the pluses and minuses do not sum simply, but rather interact in a complex manner. Herd productivity measures the net effects of various traits as O/I, a composite herd character. The output may be in biological units (e.g. pounds of sale liveweight) and input in units of land or TDN. Alternatively, output may be put in economic units by multiplying sale weight by sale price and input expressed in terms of production expenses. Herd productivity as acharacter integrated into animal breeding techniques may be placed in better perspective by reviewing the steps by which animal breeding techniques have evolved. Each of these steps has been more of an addition to rather than a replacement of the previous steps (i.e., all are useful techniques presently employed); these steps may be summarised as follows:

1. Pre-Mendelian
2. Mendelian
3. Population genetics
4. Multiple character selection
5. Quantitative genetics
6. Systems analysis

The Pre-Mendelian period was characterised by empirical methods and is the period during which many cattle breeds were developed. The rediscovery of Mendelian principles led to an understanding of how to deal with simply inherited qualitative characters. Population genetics clarified the Mendelian phenomena operating in interbreeding groups; the concepts of gene frequency, inbreeding and relationship coefficients, and quantitative genetic parameters (e.g., heritability) were developed.

The selection index introduced methods for simultaneously considering more than a single character. The concepts of relative economic value, genetic correlations and correlated response were dealt with in specific terms, and a maximising procedure was introduced. Although relative economic value was clearly defined by Hazel (1943), rigorous, realistic economic treatment has lain virtually dormant. Many animal breeders now separate population from quantitative genetics. Quantitative techniques that relate to estimating genetic parameters, such as breeding value, have been greatly enlarged and improved.

Somewhat analogous to the extension from single to multiple character selection formalised by selection index procedures, the extension from single animal to multiple animals may be formalised by a systems approach where the production unit, or herd, represents the system. The selection index treats the contribution of each of a number of characters to net worth (as defined in the index) of the individual; thus, the individual is implied as the production unit. This unrealistic simplification is theoretically dealt with by assuming that relative economic values are assigned to each unit of each character such that all of the associated inputs and outputs (costs and returns) are appropriately accounted for. The linearities assumed are difficult or impossible to accommodate and the interactions among individual animals in the production unit cannot be accounted for (Hohenboken, 1982). Systems analysis procedures more realistically account for the effects of the various traits of individuals, and interactions among individuals, on net productivity (O/I) of a production unit (Cartwright, 1979a).

The application of systems analysis techniques to livestock production systems became feasible with the advent of modern day computers. Consequently, it is sometimes assumes that systems analysis is a set of mathematical procedures more detached from production than other biological sciences. Actually, systems analysis models based on functions designed to reflect cause and effect relationships are more realistic in reflecting and understanding the biology of livestock than a statistical approach. An example of this point is illustrated by our attempts at Texas A&M to model the effects of hybrid vigour. If we simply adjust our cattle production model to increase weights and reproductive performance, as has been found in many studies, then our simulations give unrealistic results. If we knew how hybrid vigour actually operated to cause heavier weights and increased fertility, then we could model on a cause and effect basis. We have attempted to model on this basis using our best judgement. The results indicate that we can account for most of the hybrid vigour effects by modelling only an increased maturing rate potential and slightly increased feed intake capacity of the hybrid. The simulated results reflect the increased growth, fertility and other characteristics of hybrid cattle.

Our beef cattle systems analysis research indicates that, for maximal herd O/I, intermediate traits are optimal for the primary characters and that the combination depends on the market and nutritional resource. Generally, optimal size, maturing rate and milk production tend to increase as the nutritional resource increases in quality and availability. However, if the calves are finished in feedlots on relatively cheap grain, as has been the practice in the United States, then the optimal level of milk production is lower than if the calves are finished on forage. Simulation results given in Tables 1 and 2 illustrate these points.

TABLE 1: Simulated Performance of Four Cattle Herds of Two Different Genetic Size and Two Different Genetic Milk Production Potentials for a Ranch Located in Central Texas.[a]

Performance Measure	Large Size (550 kg) Heavy Milk (14 kg)	Large Size (550 kg) Light Milk (8 kg)	Small Size (450 kg) Heavy Milk (14 kg)	Small Size (450 kg) Light Milk (8 kg)
Av. 8-yr old cow wt., kg	518	519	421	422
Hay fed, av. kg/cow[b]	658	458	647	458
Av. calving percent	73.0	76.1	70.2	72.3
Av. 8 mo. wean wt., kg	244	212	216	191
Av. daily gain, kg	1.05	1.11	.95	1.01
Av. finished wt., kg[c]	466	490	415	437
Av. profit per ha, $[d]	4.55	23.98	-3.30	17.31

[a] Adapted from Stokes *et al*, (1981). These simulated output figures depend on the particular production and market parameters specified and are presented only for illustrating differences in net productivity among cattle herds of different genetic potentials. Size potential is represented by weights of mature cows at 25% body fat; milk potential is represented by the single day peak production of a mature cow.

[b] Hay was fed in amounts required to keep cows in similar condition in all size and milk levels. The pasture area available to each herd was the same; stocking rate was varied to maintain similar grazing pressure.

[c] Finished steers, placed in the feedlot immediately after weaning.

[d] The years examined were 1972 through 1978, but profit figures for the first year only are presented.

These simulations indicate that the traits for the primary characters of cattle must be tailored to the specific production environment in order to maximise efficiency. There is, of course, a practical limit to the degree of specialisation for any breed or breeder especially since the future physical and economic environment are variable and uncertain. It appears then, that both breeders and geneticists need to think more in terms of strategies to cope with both known and unknown variability. I should like to outline some ideas for research by geneticists to contribute to developing an optimal strategy and then some ideas for practising breeders.

Animal Geneticists

1. Basic research on genetic mediation of primary characters on a physiological, cause and effect basis; collaborative with nutrition, physiology and other basic sciences.

2. Systems analysis research to project research results to the context of herd production; collaborative with forage science, animal production science and economics.

3. Research to clarify the biology of ancillary characters and their relationship to animal productivity; collaborative with anatomy, parasitology, immunology and other areas.

TABLE 2: Simulated Performance for Herds Contrasting in Genetic Potential for the Primary Characters (Size, Maturing Rate and Milk Production) Located on a Ranch in The Gulf Coast Area of Texas and Kept under A Base Level and Improved Level of Nutrition.[a]

Simulated Production Measure, Herd Av.	Small Size, Slow Maturing Low Milk Production Herds[b]		Large Size, Fast Maturing, High Milk Production Herds[b]	
	Base Nutrition[c]	Improved Nutrition[c]	Base Nutrition[c]	Improved Nutrition[c]
Pregnancy, %	78	92	67	84
Weaning weight, kg	150	157	219	237
O,liveweight sold,kg I 100 kg TDN consumed	7.8	8.4	7.6	8.8

[a] Adapted from Baker (1982). THe simulated output figures depend on the particular production and market parameters specified and are presented for illustrating an environment-genetic interaction and net efficiency.

[b] The size and milk production genetic potentials, characterised in the same manner as in Table 1, are 400 and 600 kg and 8 and 15 kg/day respectively; maturing rate was decreased and increased 12% from an average value for the slow and fast maturing rates respectively.

[c] The base level represents a relatively low quality and variable forage resource and the improved level represents modest and selective increases in quality and availability of winter forage.

Animal geneticists have made extensive and good use of statistical methods. These methods have appeal because of the predictive power of statistics such as regression or genetic correlation coefficients.

These coefficients may contribute an appreciation of and knowledge about a relationship, but add little to an understanding of the processes and quantities involved in causing the observed relationship. We sometimes use a regression analysis for example, because of our ignorance of the biological processes operating in the animal system. Animal geneticists recognise the problem of inference about causal relationships drawn from regression models designed to explain the organisation of the biology. Nevertheless, geneticists tend to think of input-output relationships in terms of correlation coefficients, whereas the bases of these relationships are usually processes involving quantities and their dynamics such as the transformation and flow of matter and energy in growth, fattening and reproduction.

This type of knowledge is required to develop a model that depicts the actual biology of a cattle herd. Selection criteria, as indicated in the discussion above, should be related to net herd output. In order to evaluate the net outcome from all of the interactions, a systems analysis approach is needed. I'll return to ancillary characters after discussing the points I have listed for breeders. In order for selection to effect increased net herd productivity, we must recognise (a) that increased net herd productivity of the total production systems must be the ultimate criterion; (b) that the inputs and outputs of all the components of the production system must be included; and (c) that each production environment must be considered as a special case and dynamic. There is no single set of selection recommendations appropriate for all breeds and types of beef cattle. Also, there is no single breed that can be most productive for all components of a production system and for all production environments. Any general recommendation made about selecting beef cattle should be in terms of a strategy to cope with the complex nature of beef cattle production systems (e.g. lack of compatibility between Phase I and Phase II) and the dynamic nature of the environment. Two strategies appear to have merit; one relates to straightbreeding and the other to crossbreeding.

General selection guidelines for breeders are listed below:

Breeders

1. Selection to attain or maintain genetic potential for optimal size, maturing rate and milk production.

2. Selection to enhance ancillary characters.

3. Selection to enhance combining ability or crossbreeding complementarity.

For straightbred cattle there is obviously some compromise or intermediate point for the two primary characters of size and milk production (or weaning weight). The same points apply, in general, to maturing rate, independent of size. Size and milk production are relatively easy to evaluate and are responsive to selection. Maturing rate is much more involved and less responsive to selection. One approach is to select for rate of gain on a relative basis rather than a direct basis; that is, use rate of gain divided by average body weight over a given period of time as the criterion for selection for increasing maturing rate. Our systems analysis research indicates that in general, as nutritional quality and availability increases, the optimal size, maturing rate and milk production increase (Tables 1 and 2). In many cases we may need cattle with the genetic potential for larger size, faster growth and maturing rate, and higher milk production, but not for all cattle for all conditions and not without limit.

If the primary characters are not in close range of optimal levels for a breed or a herd, then selection to attain these levels is appropriate. Response to selection for the primary characters of size and milk production can be expected to be positive and measurable within a relatively short time.

After the primary characters have been selected to approach the optimal range, selection may be more effective in increasing production efficiency if more attention is diverted to the ancillary characters. The traits desired for these ancillary characters tend to cause fewer tradeoffs or cancelling effects between Phase I and Phase II and also tend to remain the same as market, weather and other environmental conditions change from time to time and place to place.

Plant breeders have been able to make greater improvement in crops than we have in livestock because of the biology of plants. A recent summary of the contributions of plant breeding to crop yields states that selecting crops for better adaptation to local environments accounts for much of the genetic improvement (Evans, 1980). Another major factor was adapting crops to improving and changing production conditions. A third major factor was selection for resistance to pests and diseases. I believe that animal breeders should also view improvement more in these terms; i.e., place more attention on the ancillary characters. The ancillary characters that I have listed above are not totally independent or necessarily complete. The characters included and the emphasis placed on each one may vary from breed to breed and place to place.

Reproductive soundness in females includes shape and size of udder and teats and normal development of genitalia. Age at first conception and time interval between calves should be minimal and consistent with the nutrition. Male fertility includes sound shape and size of sheath, scrotum and testes and semen volume, density, normality and motility. It has been suggested, but not fully tested experimentally, that high quality semen and other indicators of male fertility are correlated with female fertility. At the least, heifers and bulls should be expected to have heifer and bull conformation respectively; neither should be selected to resemble steers.

The fact that we have bred cattle that have calving difficulty in numbers that substantially affect productive efficiency of herds should be of concern to us. Direct selection (culling) of females and use of progeny information for sires can be practised. Muscularity must be kept within reasonable limits to avoid developing extremes that leas to calving problems (the primary reason for including muscularity in the list).

Selection for structural soundness of the entire conformation, but especially of feet and legs, of both males and females is generally recognised as useful and is usually practised reasonably well.

Adaptation to the local environment includes disease and parasite resistance. Adaptation to the local environment, especially the stresses, has become more of a potential problem because of the development of frozen semen and A.I. technology. Recent developments in immunogenetics promise to give us a future tool to aid in selecting for specific disease and parasite resistance. At this time, it is well to recognise that there is considerable variability within and among breeds in adaptation to specific locations and in resistance to diseases and parasites and to favour those breeds and individuals that thrive and produce well in the specific production environment.

Temperament is apparently fairly highly heritable. Although not well documented in research, experience supports this conclusion. Colour may be a point of preference but may also be an important feature of adaptation related to injury from solar radiation, temperature control and attraction to insects. The presence, size and shape of horns also may be a matter of preference, but may have some utility, depending on the specific conditions; e.g. polledness may be desirable in intensive operations, whereas hornedness would be advantageous under extensive operations infested with canine predators. Selection for temperament, colour and horns should be straightforward and consume only a minor amount of effort.

Crossbreeding may be used to utilise heterosis and complementarity. Heterosis is the extra vigour of the F_1 firstcross over the average of the parental breeds. There are various levels of heterosis retained in different types of crosses past the F_1 generation. The vigour of the hybrid is usually reflected in increased growth and maturing rates, net fertility and productive longevity (Long, 1980). This vigour is especially evident in the hybrid's ability to cope with stressing conditions with less adverse effects.

A crossbreeding system can overcome, to a degree, the lack of compatibility between Phase I (cow-calf) traits and Phase II (meat animal) traits by logically matching separate dam breeds, or crosses of dam breeds; and sire breeds so that each complements the other (complementarity; Cartwright, 1970). The dam breeds should be selected primarily for Phase I traits and the sire breed for Phase II traits. There are many variations of crossbreeding systems and many pros and cons of each to be considered, but judicious use of heterosis and complementarity is one way to increase real efficiency of beef cattle production systems (Gregory, 1980).

Straightbreeding has some advantages over crossbreeding and, in fact, crossbreeding depends on the existence of straightbreds. However, the traits of straightbreds desired for use in crossbreeding systems may be different from the traits for straightbred production systems.

CONCLUSIONS

In this time when the exciting developments in genetic engineering are reaching their first practical returns (e.g. production of foot and mouth disease vaccine via bacteria), we still must rely primarily on the basics of selection and breeding applications to increase productivity. The use of systems analysis techniques, made feasible by developments in operations research and computer science, provides an objective, systematic method for animal geneticists to more realistically examine net herd productivity as a "genetic character". Using measures such as herd offtake in terms of production costs for this "herd character", optimal values for the primary characters of size, maturing rate and milk production may vary for each production environment and change with time. After optimal values for the primary characters are attained for each production environment, more attention can be given to the characters related more to the structural and physiological soundness of individuals; these ancillary characters tend to create fewer complex interactions than the primary characters. Overall breeding objectives, taking into account differences among production locations and changes that may occur, should be designed as strategy to cope with the complex production process and with change. While suggesting that more specialisation in cattle breeding objectives would lead to greater net herd productivity, I also recognise that a certain amount of robustness, generalisation is needed in order to cope with uncertainty and to permit some commonality of breeding objectives and distribution of genetic improvements among breeders.

REFERENCES

BAKER, J.F. (1982). *Ph.D. Dissertation, Texas A&M Univ., College Station, Texas.*

CARTWRIGHT, T.C. (1970). *J. Anim. Sci.* *30:* 706-711.

CARTWRIGHT, T.C. (1979a). *J. Anim. Sci.* *49:* 817-825.

CARTWRIGHT, T.C. (1979b). *J. Anim. Sci.* *48:* 974-980.

CARTWRIGHT, T.C. (1980). *J. Anim. Sci.* *50:* 1221-1226.

EVANS, L.T. (1980). *Am. Scientist* *68:* 388-392.

GREGORY, K.E. and CUNDIFF, L.V. (1980). *J. Anim. Sci.* *51:* 1224-1242.

HAZEL, L.N. (1943). *Genetics* *28:* 476-490.

HOHENBOKEN, W.D. (1982). *J. Anim. Sci.* *54:* 667-679.

LONG, C.R. (1980). *J. Anim. Sci.* *51:* 1197-1223.

POWELL, R.L. and WIGGANS, G.R. (1981). *U.S.D.A., S.E.A. Dairy Herd Improvement Newsletter (April)* *57:* 5-9.

STOKES, K.W., FARRIS, D.E. and CARTWRIGHT, T.C. (1981). *Southern J. Agric. Econ.* *13:* 1-10.

TAYLOR, St.C.S. (1968). *Anim. Prod.* *10:* 157-169.